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Optimising Force Balance Exercised in the Wheel – Profile Contact Force During Curved Path. An Experimental Aproach of Using Curvilinear Profiles

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***Abstract:*— this paper objective is to contribute in the optimization of the problem of guiding forces during the movement of the railway vehicle. The work proposes an innovative solution as compared to classical author suggestions which are limited to a small number of alternatives.**

Methodology follows an experimental approach. An experiment with two stages takes place where experimental conditions are modeled after profiles designed following a curved path with 500 m radius (classified as tight curve by definition). In the first experimental stage standard profiles were used, while for the second experimental stage curvilinear profiles were exploited. After experiment conduction data concerning (1) displacement (2) moments of force and (3) guiding forces of wheel-rail contact were analyzed and compared for both stages: standard profiles and curvilinear profiles

After experimental results, major conclusions of the paper are: (1) in the case of curvilinear profiles profile, small movements of vehicle, lead to a change in the size of the wheel displacement smaller than the corresponding change in standard profiles; (2) moments of force are greater in the case of standard profiles compared to curvilinear ones; and (3) curvilinear profiles enable a movement without many contact point with the wheel, friction forces exert their action in longitudinal direction, thus by causing a smaller value of guiding forces.

***Keywords:*-- Guiding forces, curvilinear profile, moment of forces, wheel displacement.**

I. INTRODUCTION

Firstly it is important to define the meaning of “guiding forces during the movement of the railway vehicle”. According European Standards (2016), guiding force is the total of dynamic characteristics that emerges during the movement of the railway vehicle through curves. Beside ES EN 14363, UIC Code No. 518 (UIC_CODE, 2005) states that these forces emerge on each wheel during their contact with rail profiles along curves and the most important influence of this contact are: (1) wheels wear and rails wear.

These guiding forces two major component are: (1) dynamic component and (2) statistic (quasi statistic) component.

It has been early tested and approved that dynamic guiding forces cause an increase of wear index, of both the wheel and the rail, especially when the vehicle crosses curved rail section. Moreover the stronger the curve, the higher the dynamic guiding forces, and as a consequence, the higher the wheel and profile wear (Kalay, Reiff, Smith, & Choll, 2002). Strong curve is defined as a curve which is can be classified as a small radius curve, usually under the interval of curve radius under 500-650 meters (Dupont, 2011).

Given the above, it can be concluded that the movement of vehicle along a curved rail can be considered sustainable only when quasi-static component of lateral forces of interaction of wheels with rails exceeds significantly the value of dynamic forces.

Therefore, the problem that this paper addresses to, can be formulated as following: minimizing dynamic guiding forces that emerge during the interaction of train wheel and profile in curves, especially in low radius curves (strong rail curves).

Paper objective

The purpose of this paper is to achieve an alternative for reducing, or even minimizing, driving forces, that as explained in the problem identification section, emerge when train vehicle surpasses low radius curves.

Of course there are many different referencing systems from which this problem may be analyzed from, but is inevitable that resolving the train driving force in tight curves is accompanied with reducing wheel and/ or profile wear.

This paper objective is heavily conditioned by the formulation of driving force problem.

During methodology of designing a solution model for train driving force in tight curves problem, it should be considered that the following conditions have guided this design:

- This paper addresses reduction of train driving force in tight curves as a problem of reducing it dynamic

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component (not static of quasi-static force component)

- This paper focuses on driving force on horizontal (longitudinal) plane and on vertical (lateral) surfaces.
- In this work optimization object will be reduction of profile wear.

With this two conditions and restrictions in perceiving train driving force problem, it can be finally reformulated that this paper objective is to propose a technical solution that will achieve sustainable movement of the train vehicle, in low radius curves, by reducing dynamic forces which prevent wheel rolling in regard to the horizontal plane and profile consummation (profile wear).

II. LITERATURE REVIEW

The problem of addressing static guiding force reduction of train wheel and profile contact when vehicle crosses a strong curve, has been explored by a large number of authors. As a consequence, multiple solutions have been proposed.

The latest paper that addresses this problem is the one belonging to august of this year, "Optimal rail profile design for a curved segment of a heavy haul railway using a response surface approach" (Wang, Chen, Li, & Wu, 2016) . According these authors optimization is achieved in terms of minimizing rail wear, which can be achieved by implementing a genetic algorithm which encompasses the relationship between metal loss from the vehicle and coordinates on the rail.

Before this work many other authors have proposed solutions which, can be now considered as classical in terms of time of usage. But this problem continues to generate discussions among scholars because each of them wants to propose a new solution aiming at surpassing the performance of the previous solutions. Zhai, Gao, Liu, & Wang (2011) point out that the increase of train speed has aggravated furthermore the problem of vehicle guiding force presence on curved surfaces. These authors propose the implementation of asymmetric profiles in order to solve this problem.

Wilson (2006) in his doctoral thesis has concluded that majority of proposed solution for train driving forces fall within the category of designing different patterns of rail curve lubricants. Indeed work of several authors such as: Fukagai, et al. (2007), Kalay, Reiff, Smith, & Choll (2002) changes only on terms of lubrication type, application distance and other patterns.

III. METHODOLOGY

Symbolism framework

In this paper, several symbols will be used according to below meaning

d_v - Vertical wheel displacement in reference to profile

ψ - The angle of displacement of wheels in reference of their radial position;

$\dot{\eta}_w$ - Speed of lateral displacement of vehicle wheels;

$\dot{\eta}_p$ - Speed of lateral displacement of profiles.

d_h - Horizontal (longitudinal) wheel displacement in reference to profile

Δ r - Marginal value of rolling circle radius occurred during wheels lateral displacement

r_a - Average value of rolling circle radius;

ρ - Value of the bending level of profile under vehicle wheels couple

$\dot{\psi}$ - Velocity of wheel movement in horizontal plane

bs – Half of the distance between the circles of wheels rolling

Theoretical apparatus

As was previously explained in the problem identification section, classical formulation of guiding forces emerging during wheel – profile contact is characterized by both: lateral (horizontal) guiding force and vertical force, as represented in Figure 1.

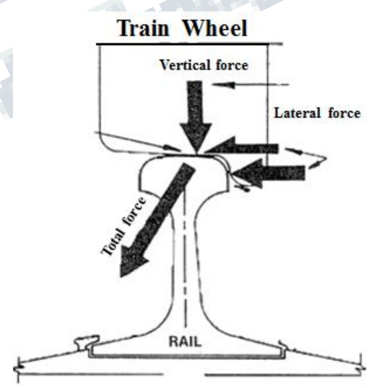

Figure 1 Graphical representation of guiding forces on wheel – profile contact

In order to describe the above situation in terms of two components of total driving force resulting in wheel – profile contact, the indicator of wheel displacement will be used. Analytically, Figure 1 is represented by equations (1) and (2), derived from non – linear theory developed by (Wolves, 2013), as explained in below paragraphs.

On one hand, vertical wheel displacement in reference to profile is determined by the equation:

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$$d_v = \psi - \frac{1}{V}(\dot{\eta}_w - \dot{\eta}_p) \ ,$$

On the other hand, horizontal (longitudinal) wheel displacement in reference to profile is determined by the equation:

$$d_h = \Delta r * r_a^{-1} + b_s(\rho - \dot{\psi} * V^{-1}) \, ,$$

What can be concluded from the above equations is that vertical wheel displacement is mainly determined by ψ- the angle of displacement of wheels in reference of their radial position[1]; while longitudinal wheel displacement in reference to profile is mainly determinate by rotation angle of the pair of wheels. Of course all the above logic and analysis is worth in the situation of tight curve surfaces.

In the case of nonlinear trajectory, as a result of angular and longitudinal relationship, frictional force of all couple of wheels, form additional moments, which increase the guiding forces. Therefore in this paper vehicle movement in curves will be described in terms of: (1) displacement, (2) moments and guiding forces.

IV. DATA ENTRY AND ANALYSIS

This paper will follow a simulation methodology for data entry and analysis. For experimental purposes, a two-step approach is implemented. The two experimental stages were characterized by profiles designed following a curved path with 500 m radius (classified as tight curve by definition.

In the first experimental stage standard profiles were used, while for the second experimental stage curvilinear profiles were exploited. After experiment conduction data concerning (1) displacement (2) moments of force and (3) guiding forces of wheel-rail contact were analyzed and compared for both stages: standard profiles and curvilinear profiles

V. RESULTS AND DISCUSSIONS

Wheel displacement

In the Figure 2 are presented results for both stages of experiment (standard and curvilinear profiles) in terms of wheel displacement of the first and second pairs of wheels. As was previously presented both profiles are designed according a curve with radius 500m.

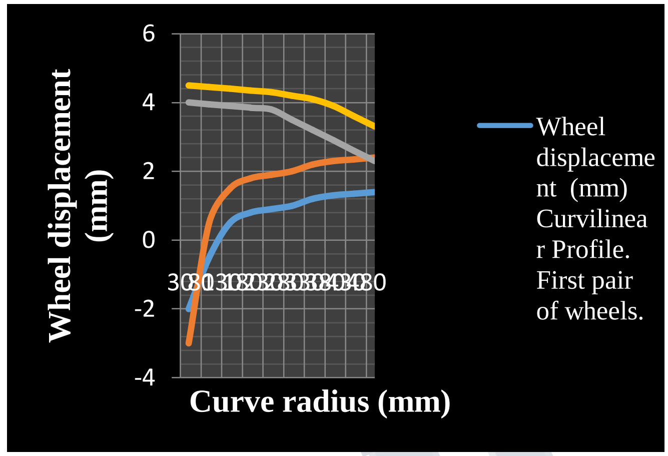

Figure 2 Wheel displacement of pairs of wheel (a) first pairs of wheel, (b) second pairs of wheel

This graph confirms that usage of curvilinear profiles reduces wheel displacement. This lowers friction forces, thus influencing in reduction of wear. By applying equation (1) and (2), the above graph has suggested that in the case of curvilinear profiles profile, small movements of vehicle, lead to a change in the size of the wheel displacement smaller than the corresponding change in standard profiles.

Moment of Forces

In the Figure 3 are presented results for both stages of experiment (standard and curvilinear profiles) in terms of moment of forces of the first and second pairs of wheels.

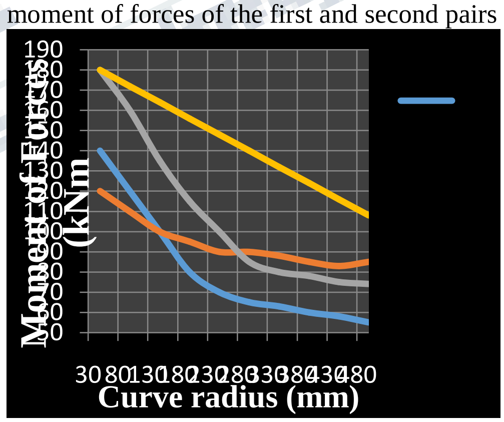

Figure 3 Moment of forces : (a) longitudinal forces, (b) lateral forces

As may be observed from the above graph, moments of force are greater in the case of standard profiles compared to curvilinear ones. This is a consequence of the fact that the need for a sufficient space for the movement of wheels on curvilinear profiles is greater than in standard ones.

This experiment confirmed that in curvilinear

[1] Reduced by usually low value of $\frac{1}{V}(\dot{\eta}_w - \dot{\eta}_p)$, expression

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profiles with the increasing radius of the curve, moment of forces in the longitudinal direction in curved trajectories, significantly contributing to the reduction of the moment; as compared to standard profiles.

Guiding forces

In the Figure 4 results for both stages of experiment (standard and curvilinear profiles) in terms of total guiding forces.

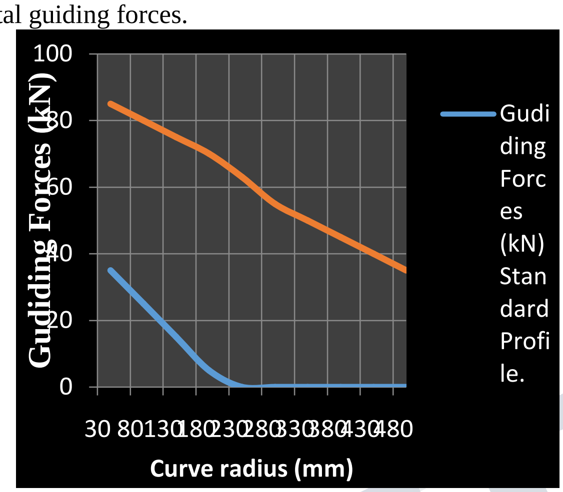

Figure 4 Guiding Forces

This is the most important indicator of the paper. From the above graph it can be stated that curvilinear profiles enable a movement without many contact point with the wheel. This is because in strong curves, as was previously tested, friction forces exert their action in longitudinal direction, by lowering the value of guiding forces. In contrary, standard profile is characterized by two contact points even in curved sections.

VI. CONCLUSSIONS

This paper has tested the influence of profile type on wheel- profile contact patterns. After experimental simulation this work has analyzed if curvilinear profiles can impact: 1) displacement (2) moments of force and (3) guiding forces of wheel-rail contact as compared to standard profiles.

After experimental results, major conclusions of the paper are: (1) in the case of curvilinear profiles profile, small movements of vehicle, lead to a change in the size of the wheel displacement smaller than the corresponding change in standard profiles; (2) moments of force are greater in the case of standard profiles compared to curvilinear ones; and (3) curvilinear profiles enable a movement without many contact point with the wheel, friction forces exert their action in longitudinal direction, thus by causing a smaller value of guiding forces.

Usage of curvilinear profile causes a redistribution of forces and friction vectors, thus allowing change (1) in friction and (2) lateral forces.

Given that these changes, deriving from usage of curvilinear profiles impact wear level, this paper results impact the optimization of wheel – profile contact in curved segments.

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